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(54) A method of making wear resistant gray cast iron.

(57) A method is disclosed for making gray iron having both increased wear resistance and impact toughness, comprising: (a) solidifying a hypoeutectic gray iron melt (i) to which has been added a carbide forming agent in an amount of .3-.8% by weight, selected from the group consisting of Ti, V and Mo, and, advantageously, a high carbon austenite-ferrite forming agent in an amount of .5-3.0%, by weight, selected from the group consisting of nickel and copper, and at a solidification rate to form a matrix with a mixture of flake graphite and eutectic carbide suspended in the matrix; and (b) heat treating the solid by (i) heating to a temperature and for a period of time to fully austenitize the solid (ii) quenching the solid to a temperature level and for a period of time to decompose austenite to form and high carbon austenite and ferrite matrix and (iii) air cooling the solid to room temperature.

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(WHITE)
AUSTENITE
FERRITE
NATRIX
(BLACK)
FLAKE
GRAPHITE
(GRAY)
EUTECIC CARBIDE
500X

FIG.1

A METHOD OF MAKING WEAR RESISTANT GRAY CAST IRON.

The invention relates to a method of making wear resistant gray cast iron.

Grey cast iron is the least expensive of all the cast metals. This is due to the type of raw materials used: pig iron, cast iron scrap, steel scrap, limestone, coke and air, all of which are relatively inexpensive. Most gray cast iron used commercially is used primarily in the as-cast condition. There has been some attention to heat treatment and low alloying for grey cast irons through the years.

The general consensus of foundry operators in this country indicates that the composition of gray cast iron should be about (using weight percentages here and throughout the description); 2.0-4.0 carbon; 1.25-3.25 silicon; .75-1.25 manganese; .08-.12 sulfur; and .07-.20 phosphorus.

In the field of abrasive wear, gray cast iron is usually used where the required impact toughness in service is not severe. Such cast iron is resistant to abrasive wear because of the presence of a high amount of carbides in the matrix of the cast iron. Most gray cast irons will contain at least 10% by weight primary complex iron carbides. Unfortunately, however, these carbides are normally massive and impart a degree of brittleness to the cast iron which considerably limits its usefulness with reference to impact strength. While relegating gray cast iron to applications without the need for high impact strength, the main developmental effort has been to improve machining.

One attempt to provide greater machinability while retaining excellent wear resistance and fatigue resistance of gray cast irons involves heat treating the as-cast iron to reduce hardness while retaining the carbidic microstructure (see U.S. patent 4,230,506). In this patent, the cast metal was alloyed with a combination of carbide forming agents such as chromium, nickel, copper, molybdenum, and vanadium. They were used in combination to provide a composite total in an amount of 2.25-3.85%; this is a considerable amount of carbide forming agent. The improvement in machinability was achieved by heat treating to an austenitizing temperature, slowly cooling over a period of 1-1/2 hours to a temperature level of 400°F, and then air cooling. Slow cooling promoted the production of pearlite and reduced the hardness of such cast iron, making it more readily machinable. After machining, the iron was quenched to transform any retained austenite to martensite.

The problem with the 4,230,506 patent is that wear resistance is retained or improved at the sacrifice of toughness and strength characteristics, making it unsuitable for applications that require a high level for both of these characteristics.

Similarly, in U.S. patent 3,384,515, the solution to the problem of machinability was to control heat treating to permit the promotion of complex iron carbides while providing for incipient spheroidization of pearlite, thereby avoiding martensite and reducing the hardness of the material. The same problem with respect to lack of enhancement of toughness and strength characteristics in such a carbidic cast iron remains.

In U.S. patent 2,885,284, an attempt was made to provide for an increase in both the abrasive wear as well as the impact properties of the gray cast iron. The contribution of this patent is to incorporate high amounts of alloying ingredients in the form of aluminum and manganese to promote contrary characteristics. Aluminum is added in amounts greater than 1% to promote graphitization and manganese is added in amounts greater than 1.5% to promote carbide stabilization. There is no attempt to modify or introduce any unusual heat treating parameters; there is simply a reliance upon conventional processing and heat treating steps. The disclosure admits, in column 2, lines 27-33, that the amount of aluminum or manganese that is incorporated will depend upon which characteristic is desired in the final product, namely, to increase toughness the carbon must be predominantly in the form graphite promoted by the use of aluminum, and to provide for increased hardness the carbon must be predominantly in the form of carbides, which is promoted by the incorporation of manganese. This disclosure is an "either/or" teaching in that the there is no suggestion that both of such characteristics can be achieved at a high level at the same time.

It is an object of this invention to provide a gray cast iron having both increased wear resistance and toughness which can be achieved by modification both in the chemistry and the heat treating techniques for gray cast iron.

In addition, it is an object of this invention to provide the above type of gray cast iron which additionally has high tensile strength, high damping capacity, high heat conductivity, and more ductility than conventional cast irons.

According to the present invention there is provided a method of making a wear resistant gray cast iron comprising, a solidifying a hypoeutectic gray iron melt to which has been added a carbide forming first agent in an amount of .3-.8% by weight, selected from the group consisting of titanium, vanadium, and molybdenum, said solidification being at a rate to form a matrix with a mixture of flake graphite and eutectic

carbide suspended in said matrix, and heat treating said solid by (i) heating to a temperature and for a period of time to fully austenitize the solid, (ii) quenching said solid to a predetermined temperature level and holding at said level for a period of time to decompose austenite to form a high carbon austenite and ferrite matrix, and (iii) air cooling the solid to room temperature.

The hypoeutectic gray iron contains less than 4.35% carbon equivalent and preferably comprises, by weight, 2.5-3.0% carbon, 2.0-2.5% silicon, .5-.90% manganese, and the remainder iron.

Preferably, the heat treating comprises heating to a temperature level of 849-866°C (1560-1590°F) for a period of time of 1.5-2.5 hours; and the quenching step comprises quenching to a temperature level of 232-371°C (450-800°F) for a period of time of 1.5-2.5 hours. The rate at which such quenching is carried out is preferably in the range of 149-196°C (300-375°F) per minute.

The resultant cast iron will comprise a microstructure preferably having the suspended mixture comprised of 40-60% flake graphite and the remainder of the mixture eutectic carbide. Such mixture is controlled by the selection of the solidification rate and by the selection of chemistry for the gray cast iron melt. The casting will preferably have a tensile strength of 45-55 ksi, an impact strength of 30-35 ft/lb, and an elongation of about 2%. The wear resistance of such casting is 2-3 times greater than conventional gray cast irons and when measured by a standard sleeve test is .0028-.0019 inch per 1000 hours. The casting also is characterized by resistance to scuffing whereby the ratio of horsepower to produce scuffing divided by the normal horsepower is greater than 1.5. These wear resistance parameters are achieved through attainment of a type A graphite flake in the casting.

The invention will now be further described by way of example with referance to the accompanying drawings in which:

Figure 1 is a photo-micrograph of the structure of the casting produced by the method of this invention, the microstructure being shown at an enlargement of 500×. Areas of flake graphite, eutectic carbide, and austenite ferrite are indicated.

The preferred method for making a gray cast iron having both increased wear resistance and impact toughness comprises: (a) solidifying a hypoeutectic gray iron melt (i) to which has been added a carbide forming first agent in an amount of .3-.8% by weight, selected from the group consisting of titanium, vanadium, chromium, and molybdenum, and a second agent to facilitate the formation of high carbon austenite-ferrite, said second agent being present in an amount of .5-3.0% by weight, selected from the group consisting of nickel and copper and (ii) at a solidification rate to form a matrix with a mixture of flake graphite and eutectic carbide suspended in the matrix; and (b) heat treating the solid by (i) heating to a temperature and for a predetermined period of time to fully austenitize the solid (ii) quenching the solid to a temperature level and for a period of time to decompose austenite to form a high carbon austenite-ferrite matrix and (iii) air cooling the solid.

Chemistry

A conventional wear resistant gray iron usually contains 3.0-4.0% carbon, 1.5-3.0% silicon, and .5-.9 manganese. This method lowers the carbon content and adds both a carbide forming agent and an agent to facilitate the formation of high carbon austenite-ferrite during heat treatment. The carbide forming agent is made in addition to the normal carbide forming tendencies of manganese which is a normal part of gray cast iron. Aluminum is specifically absent from the present chemistry because it is a graphitizer which works against carbide formation and encourages pin hole defects. The addition of a graphitizing agent is conspicuously absent from the present invention because graphitization can be controlled through process parameters with a given lower amount of carbon.

Specifically, the chemistry comprises, preferably, 2.5-3.0% by weight carbon (a hypoeutectic iron-carbon alloy would comprise less than 35% carbon equivalent). If the carbon content were to be below 2.5%, it would be difficult to provide the desired amount of carbide/graphite ratio (40:60 to 60:40) that is necessary for the wear resistance of this invention. If the carbon content were in excess of 3%, processing parameters would tend to form an excessive amount of graphite. It is desirable for the starting melt for this invention that it have a carbon equivalent in the range of 3.2-4.35 because below 3.2 too much carbide is formed, and above 4.35 too much graphite is formed, making it difficult to control the graphite/carbide ratio. Silicon is present in an amount of 2.0-2.5% and manganese remains at .5-.9%. If the silicon and manganese contents were to be below the designated amounts of 2.0 and .5%, respectively, there would be insufficient volumes of graphite or carbide formation; if the upper limit of manganese was exceeded, Mn segregation will occur and a nonuniform matrix structure will result. If the upper limit of silicon is exceeded, excessive carbide and/or graphite formation will occur.

The additional carbide forming agent, which is added to the gray iron melt herein, comprises molybdenum, titanium, chromium, or vanadium. Any one or all of these ingredients may be added as long as they are present in the alloy melt in an amount in the range of .3-.8% as combined. If less than .3% is employed, the carbide volume will be too low; if greater than .8% is employed, then too much carbide will be present.

In order to promote the decomposition of austenite into high carbon austenite and ferrite, without the formation of pearlite or martensite, during the heat treatment and cooling sequence, it is desirable to add either nickel and/or copper in an amount of .5-3.0%, which functions as a pearlite suppressor and thus an austenite-ferrite former. If the amount of these elements, singly or combined, were to be below .5%, then pearlite formation in larger castings will occur, and if exceeding 3.0%, the alloying agent would be wated and is uneconomical.

The above melt is fully solidified at a rate over a period of 4-16 minutes to ensure the formation of a carbon mixture in the form of 40-60% by volume graphite and the remainder eutectic carbide.

Processing

The solidification of the melt as indicated above is then subjected to a heat treatment sequence which comprises heating to an austenitizing temperature in the range of 1560-1590°F (848.9-865.6°C) and held at such temperature for a period of 1.5-2.5 hours, during which time the casting will be fully austenitized. The casting is then quenched to a temperature level of 450-800°F and held for a period of 1.5-2.5 hours. The quench rate should be in the range of 300-375°F per minute. If the quench rate were to be slower than 300°F per minute, the opportunity for formation of pearlite would be increased. If the quench rate were to exceed 375°F per minute, the tendency for forming quenching cracks (due to high thermal stresses) would be experienced. The quench rate is important because it attempts, by way of processing, to determine the desirable matrix of austenite and ferrite. By observing the quench rate and the required chemistry, such heat treatment sequence will result in a cast iron matrix of austenite-ferrite having a suspended carbon mixture in the form of 40-60% flake graphite and the remainder in the form of eutectic carbide particles. This proportioned mixture is one of the key aspects of providing for simultaneous enhancement of wear resistance and impact resistance.

Following the decomposition of austenite to high carbon austenite and ferrite, the casting or solidification is then cooled to room temperature by air cooling.

Microstructure

The resulting casting will have a microstructure which consists of a high carbon austenite and ferrite matrix with a suspended mixture of flake graphite and eutectic carbide particles. There is a conspicuous absence of martensite or pearlite in the microstructure. The suspended mixture particles constitute about 20% by volume of the microstructure. The graphite particles will be in the form of type A flake graphite because of good inoculation using ferro-silicon. Such type A graphite will influence the damping capacity, thermal conductivity, and machinability of the gray cast iron.

The physical characteristics of such gray cast iron will have a wear resistance which is at least 2-3 times greater than that of conventional gray cast irons, and with the limited samples that have been tested to date the wear resistance shows .0028-.0019 inch per 1000 hours of a conventional sleeve test, such test being outlined in the Metals Handbook.

In addition, the wear resistance is characterized by resistance to scuffing wherein the ratio of horsepower to produce scuffing divided by the normal horsepower is greater than 1.5. Gray cast iron, having a type A graphite in a martensitic matrix, normally exhibits a resistance to scuffing in the range of 1.39-1.45.

The impact resistance was tested to be in the range of 25-35 ft/lbs, where a conventional gray cast iron has a charpy notch impact value normally in the range of 1-2 ft/lbs.

The tensile strength of such resultant cast iron is 45-55 ksi, which is in the high range for gray cast iron, and elongation of about 1-2%. The hardness for such material is the range of 160-248 BHN.

Examples

Several examples were prepared by melting a gray iron starting material which consisted of silicon in an amount of 2.3%, manganese .6%, with phosphorus being .12%, and sulphur being .10%. The carbon content of the gray iron was varied according to that shown in Table I along with variations in the added carbide forming agent, and variations in the addition of nickel as an agent to encourage the decomposition of austenite to high austenite and ferrite. Heat Treatment was employed as indicated (such treatment being to heat the casting to 1570°F for two hours, quench to 600°F, and hold for two hours, then air cool). The wear resistance and impact resistance were recorded for each such example.

TABLE I

Sample	Carbon Content (Wt.%)	Carbide Former Additive (Wt.%)	Austenite/ Ferrite Promoter (Wt.%)	Heat Treatment Applied	Wear Resistance	Impact Resistance (ft/lbs)
1	3.5	None	None	No	Poor	2
2	3.0	Mo/.5	"	Yes	Moderate to Good	5
3	"	"	Ni/2.0	"	Good	30
4	"	Ti/.5	"	"	"	31
5	"	Cr/.5	"	"	"	30
6	"	V/.5	"	"	Very Good	32
7	2.0	Mo/.5	"	"	Good	1 (damping very low)
8	3.0	Ti/.1	"	"	Poor	25
9	"	Mo/.1	None	"	Poor	3

Claims

1. A method of making a wear resistant gray cast iron comprising, a solidifying a hypoeutectic gray iron melt to which has been added a carbide forming first agent in an amount of .3-.8% by weight, selected from the group consisting of titanium, vanadium, and molybdenum, said solidification being at a rate to form a matrix with a mixture of flake graphite and eutectic carbide suspended in said matrix, and heat treating said solid by (i) heating to a temperature and for a period of time to fully austenitize the solid, (ii) quenching said solid to a predetermined temperature level and holding at said level for a period of time to decompose austenite to form a high carbon austenite and ferrite matrix, and (iii) air cooling the solid to room temperature.

2. A method as claimed in Claim 1, in which said solidifying step additionally comprises adding a high carbon austenite-ferrite forming agent in an amount of .5-3.0%, selected from the group consisting of nickel and copper.

3. A method as claimed in Claim 1 or 2, in which said hypoeutectic iron contains less than 4.35% carbon equivalent.

4. A method as claimed in any one of Claims 1 to 3, in which said hypoeutectic gray iron melt comprises, by weight, 2.5-3.0% carbon, 2.0-2.5% silicon, .5-.9% manganese, and the remainder iron.

5. A method as claimed in any one of the preceding claims, in which said heating is carried out at 849-866°C (1560-1590°F) for 1.5-2.5 hours.

6. A method as claimed in any one of the preceding claims in which said quenching is carried out at 232-371°C (450-800°F) for 1.5-2.5 hours.

7. A method as claimed in Claim 6, in which said quench rate is 149-196°C/minute (300-375°F/minute).

8. A method as claimed in any one of the preceding claims, in which said mixture is comprised of 40-60% flake graphite and the remainder of said mixture being eutectic carbide particles.

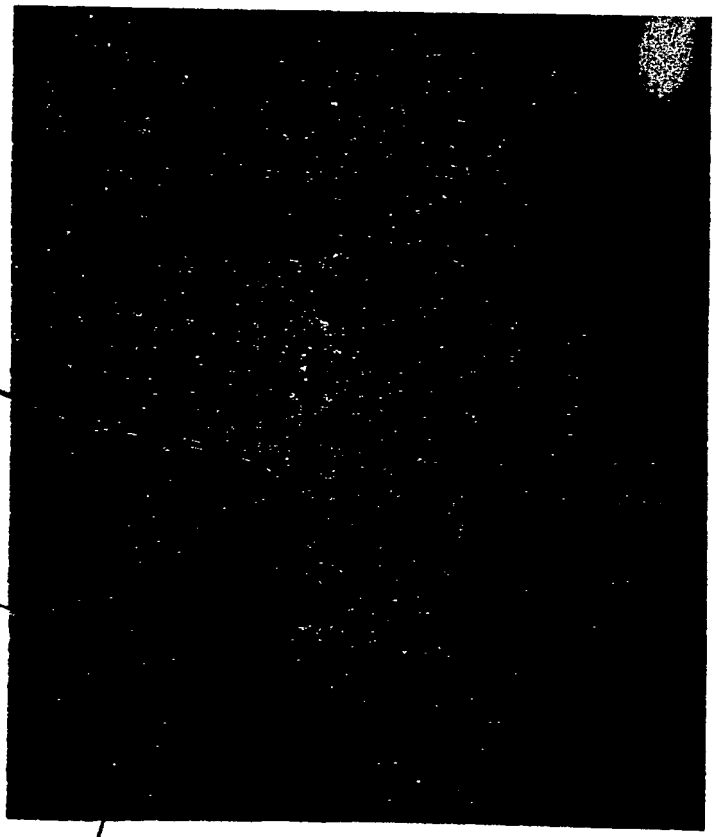
(WHITE)
AUSTENITE
FERRITE
NATRIX
(BLACK)
FLAKE
GRAPHITE
(GRAY)
EUTECIC CARBIDE
500X

FIG.1

European Patent Office

EUROPEAN SEARCH REPORT

Application Number

EP 87 31 0035

DOCUMENTS CONSIDERED TO BE RELEVANT

Category	Citation of document with indication, where appropriate, of relevant passages	Relevant to claim	CLASSIFICATION OF THE APPLICATION (Int. Cl.4)
Y	EP-A-0 174 087 (FORD) * Claims *	1-6	C 21 D 5/00 C 22 C 37/00
Y	FR-E- 89 010 (RENAULT) * Abstract; examples *	1-6	
A	PATENT ABSTRACTS OF JAPAN, vol. 10, no. 71 (C-334)[2128], 20th March 1986; & JP-A-60 211 050 (TEIKOKU PISTON RING K.K.) 23-10-1985		
A	GB-A- 545 102 (MOND NICKEL)		
A	GB-A- 840 490 (GOETZEWERKE)		
A,D	EP-A-0 018 703 (TEXTRON)		
A,D	US-A-3 384 515 (A.D. ALKERMAN et al.)		
A	METAL PROGRESS, vol. 128, no. 2, July 1985, pages 19-26, Metals Park, Ohio, US; R.B. GUNDLACH et al.: "Austempered ductile iron combines strength with toughness and ductility"		TECHNICAL FIELDS SEARCHED (Int. Cl.4) C 21 D C 22 C

The present search report has been drawn up for all claims

Place of search	Date of completion of the search	Examiner
THE HAGUE	29-02-1988	MOLLET G.H.J.

CATEGORY OF CITED DOCUMENTS

X : particularly relevant if taken alone
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